Music score elicits neuronal activation in the temporal region

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1 Introduction

Effects of long-period musical training from childhood on the brain have been studied psychologically [1], anatomically [2], and functionally [3-6]. Absolute pitch, which is the ability to identify the note of a tone without any reference, is one of the most outstanding results of musical training. It seems that possessors of the absolute pitch have a memory of musical pitch in their brain. A PET study on musicians reported the brain regions, which were activated by musical tone-interval judgment task [7]. To our knowledge, there is no report on the time course of the brain activation during pitch recalling. On the other hand, some absolute pitch possessors claimed that they need help of the name of the tone when they sing a song with correct pitch. Such internal experience suggests a relationship between the memory of pitch and language. In this study, we investigated the neural activities while absolute pitch possessors recalled the pitch memory by MEG that has high spatio-temporal resolution.

2 Materials and methods

Subjects

Ten Japanese female college students majoring in music (age 18-24 years) participated in this experiment. All except one of them specialized in piano and had been practicing piano from the age of 3-5. The subjects claimed to be able to recall the pitch by viewing a note. The possession of absolute pitch was confirmed by a greater than 90% correct response to 50 different piano tones in a screening procedure, in which they were asked to identify the note of the piano tones. Five musicians were classified as absolute pitch possessors (APs), and other five as relative pitch possessors (RPs). All subjects were judged as right-handed by the Edinburgh handedness questionnaire [6] and reported no history of hearing loss.

Stimuli

Quarter-notes of four different keys were visually presented to subjects in random order with SOA of 1.5–2.0 s on a white background of 1.9 x 1.5 degree visual angle (Fig. 1a). The subjects were instructed to watch the note and recall the pitch when the notes appeared one after another. Total 440 stimuli were presented to the subjects. In a control condition (Fig. 1b), a deformed quarter-note flashed with the same SOA on the same white screen. The subjects watched this symbol and counted silently its occurrence.

In order to record auditory evoked fields in a separate run, a pure tone (1kHz) was presented to the subject's ears with ISI of 1.35-1.85 s and the intensity of 65 dB SPL.

MEG recordings and Data analysis

Magnetic fields from the subjects were recorded with a whole head SQUID magnetometer system (Neuromag, Vector View^{TM}). The recorded MEG data were collected into epochs of 900-ms duration, including a 300-ms pre-trigger. After the epochs containing EOG more than 150 μV were rejected, they were collected, averaged, and digital-filtered to 0.2-30 Hz. In order to evaluate the peak latency and amplitude of MEG response, root mean square (RMS) values of the sensors, which were located in anterior and posterior temporal channels, were calculated for each hemisphere of the subject for each condition (see Fig. 2). Single-dipole model or two-dipole model was applied for the dipole estimation. The calculated dipoles were selected on the basis of a goodness-of-fit (GOF) of greater than 85%, an index of agreement between the observed and calculated magnetic fields, and stability of the calculated single dipole in position over 10 ms latencies.

Behavioral measurements

To estimate the length of time the subjects took to recall the pitch, the reaction time (RT) was measured after MEG recording using the same stimuli. The RT was also measured for the simple reaction time. The subjects were asked to press the key at the moment when they recalled the pitch in the former case, and when the note appeared on the screen without recalling the pitch in the latter. In both data, RTs within 100 ms were discarded as erratic.

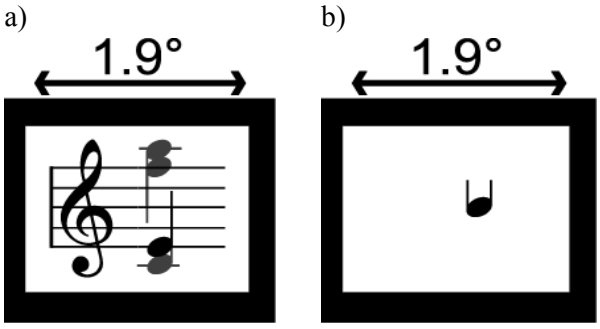

Figure 1**:** *a) Note stimuli for recalling the pitch: four quarter-notes flashed randomly with SOA of 1.5-2.0 s, and b) symbol stimuli for control measurement: a deformed quarter-note flashed and stayed in the same position.*

3 Results

3.1 Reaction time

The mean RT (and standard deviation) for the simple reaction without pitch recalling was 220.8 (33.4) ms in AP subjects and 242.8 (29.2) ms in RP subjects. The mean RT for recalling the pitch was 310.6 (87.5) ms for AP and 412.0 (104.3) ms for RP. In individual subjects, the recalling RT was 40-300 ms longer than the RT of simple reaction (two-tailed paired t-test, for AP: $p<0.04$, for RP: $p<0.01$). We concluded that 400 ms from the onset of the stimuli was enough for an analysis of the task.

3.2 MEG responses

The RMS amplitude of the MEG response showed large variability among subjects. Figure 2 shows the four sensor areas, which exhibited large deflections of MEG response, and the RMS amplitude of these sensors. The responses from the posterior temporal sensors were observed in latency periods of 130-190 ms and 200-300 ms for both note and symbol stimuli, where these responses were enhanced by pitch recalling. The dipoles of these responses were localized in the ventral-occipital to lateral-occipital region. The responses from the anterior temporal sensors were observed in latency periods of 150-170 ms, 220-270ms, and 350-380 ms. Dipoles of these responses were localized around the auditory cortex,

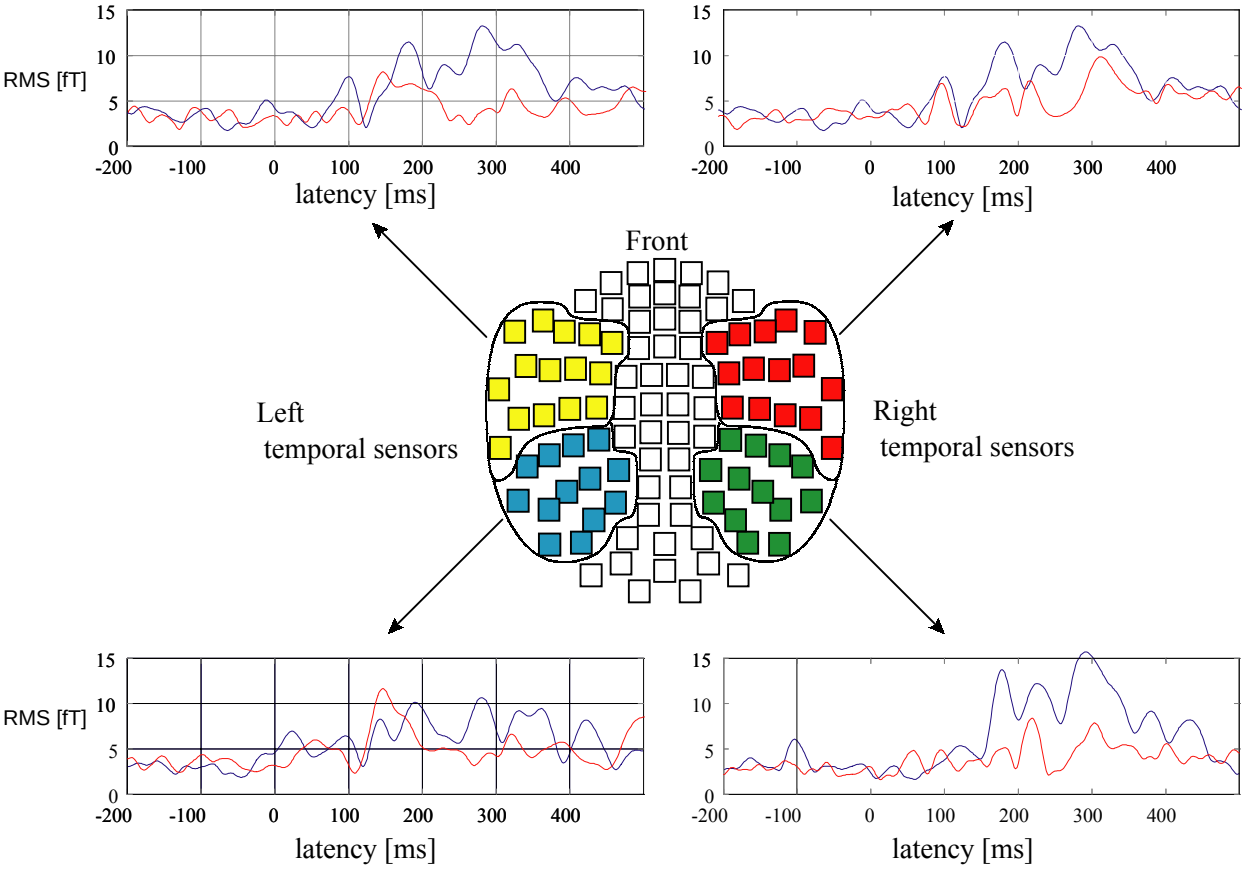

Figure 2: RMS amplitude of MEG responses recorded by the sensors located in the anterior and posterior temporal parts of the brain. The blue and red line indicates the results for the note and symbol task, respectively.

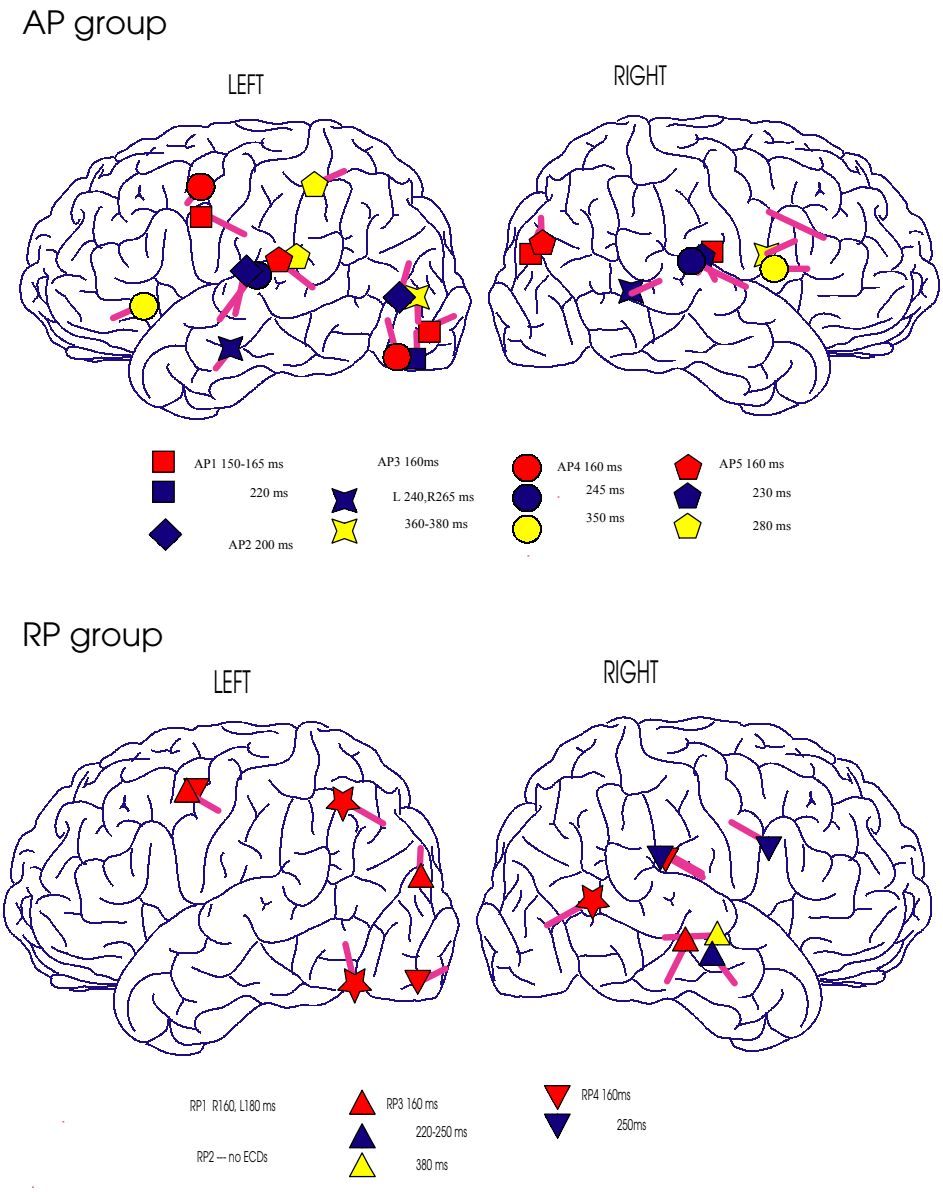

Figure 3: Location of localized dipoles superimposed on a schematic brain. A bar on each dipole indicates the direction of dipole current.

posterior end of the lateral sulcus, and frontal lobe. Figure 3 illustrates summarized results of the dipole locations on a schematic brain surface.

4 Discussion

The occipital visual cortex was activated by both note and symbol stimuli. The activities in the occipital region may be related to visual processing that is common to both tasks. Recalling the pitch of musical notes seems to take more concentration than counting visual stimuli. The observed enhancement of the activities in visual cortex might reflect the degree of the concentration.

The calculated dipoles clustered around occipital, temporal, and frontal regions, but the latency range of the dipoles varied among subjects. Such different latencies of activation may be due to strategic difference by subjects for pitch recalling.

An fMRI study using visually presented text and music score showed the music specific activity in the right transverse occipital sulcus [8]. In this study, however, dipoles were not commonly observed across subjects in the right occipital region. In the right posterior temporal region, RMS amplitude of

the MEG response was increased, but reliable dipoles were not localized.

Some subjects showed activities in the frontal cortex. A PET study in which musicians discriminated tones revealed the activity in similar region [9]. These activities probably reflect the process related with working memory and learning.

The temporal regions like superior temporal sulcus and angular gyrus are reported as language related cortex [10-12]. The activities from these regions may indicate that the musicians use language related strategies for recalling pitch.

In general, children learn musical instruments, such as a piano, while singing the name of notes. It is thought that perfect pitch possessors memorize the frequencies of the notes with its name. Such musical training may lead to an automatic reaction to retrieve the pitch with its name when they view notes. This automatic function might be the basis of the activities localized near the auditory cortex.

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